

A Programmatic Approach to On Condition Maintenance

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Background - Where we started

- **Purchased 80 COTS Honeywell Model 8500C Balancer/Analyzer, as existing equipment was not supportable (1.56 M, FY 96)**
- **Engine Front Frame Cracking #1 Safety Issue**
 - Vibration due to poor RT&B causing cracking
 - Excessive #1 Bearing oil leakage, ingested by engine, caused in-flight emergency engine shut downs
 - Costs squadron man-hours and engine replacement
- **Premature structural and hinge point failures experienced**
- **New RT&B procedure successfully developed to eliminate engine front frame cracking**
- **DCC-81 Modified rotor blades (105K, FY 97)**
- **Elimination of Whirl Tower saved \$5M Annually**

Drive to utilize equipment to its capacity

Phase I

Getting Started and Setting the Foundation



- **COTS equipment could collect vibration data**
- **COTS software needed to automate the O level aspect of the analysis**
- **Develop the frequency models of the engine and drive train**
- **Optimize sensor locations through surveys and initial testing**
- **Collect data that can help establish good vibration limits**
- **Validate the system approach before fleet implementation**

- **Merely collecting data without having tools to drive real world interpretation will lead to failure**
- **Limits and data collection sequences must be modifiable by the Navy Engineering Staff**
 - **Older Vibration Equipment required the vendor to modify software any time a change was needed**
- **Software should keep it simple for the end user**
- **Maintenance manuals should interface with analysis system**

- **Teach the theory, not just the how**
- **Instructional and practical/hands-on methods required**
- **Share results**
- **Empower the user to be a part of the system developments/enhancements**
- **Technical representatives at the sites are key to success**

Communicate system benefits through training

Phase II

Periodic Vibration Checks



Slow methodical implementation

- **100 hour/phase checks increased knowledge**
- **Gained momentum as troubleshooting tool**
- **Maintenance time decreased**
- **Data review identified issues we never could have seen with previous test methods**
- **Allowed us to evaluate effectiveness before spending a lot of money**
- **Avoids false removals / A799 rates**
- **Able to grant high time component life extensions**
- **Fleet demand drove follow-on buy of 30 more 8500C units (780K, FY 98)**

Early steps realized significant savings

- **High Speed Shaft Resonance**
- **High Speed Shaft Adapter Imbalance**
- **Main Electrical Generator failures**
- **Service life extensions for aft transmissions**
- **Excessive engine vibrations**

High Speed Shaft Resonance

Problem

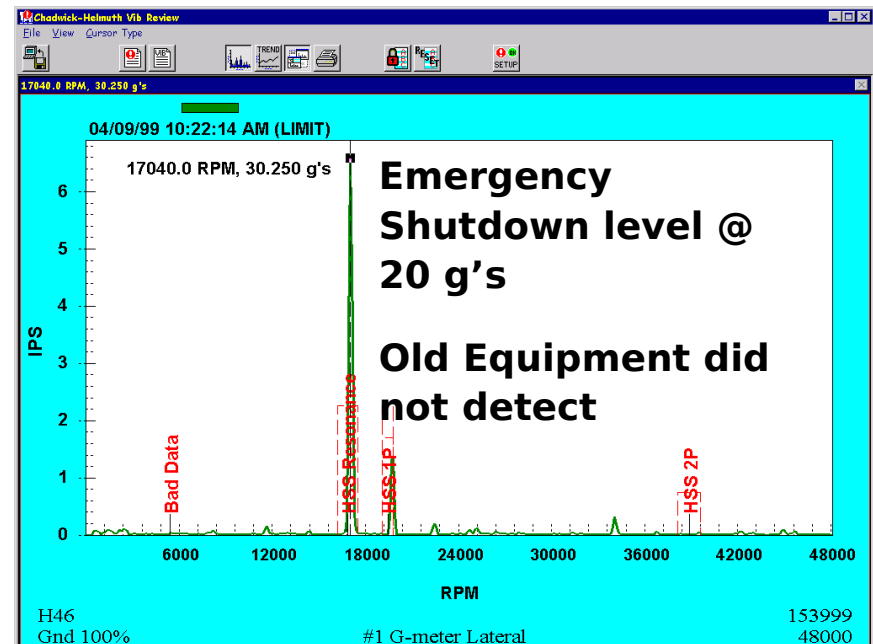
- Damaged torque sensors
- Erroneous torque readings

Findings

- Spline wear allowing resonance in HSS
- HSS resonance undetected with previous equipment
- Pilots troubleshooting by throttling the engine back and causing resonance
- Spectral analysis equipment can detect resonance

Resolution

- Inspection of spline wear implemented
- Check for resonance with use of narrowband equipment when erratic torque readings reported
- Pilots instructed to operate at 100% Nf/Nr



High Speed Shaft Adapter Imbalance

Problem

- Increase in shaft removal & rejection
- Seals failing
- Engines and transmissions were being removed

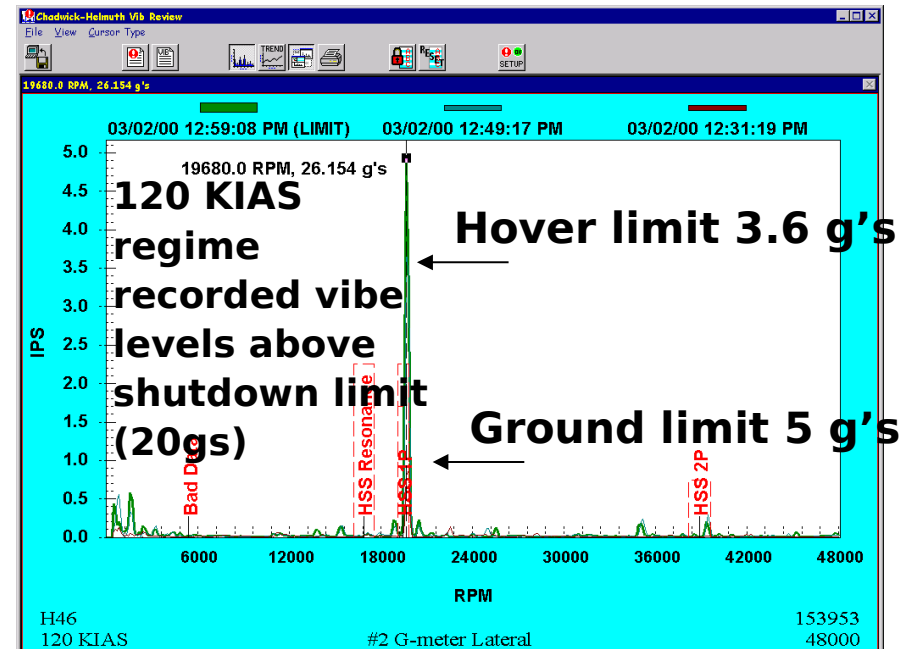
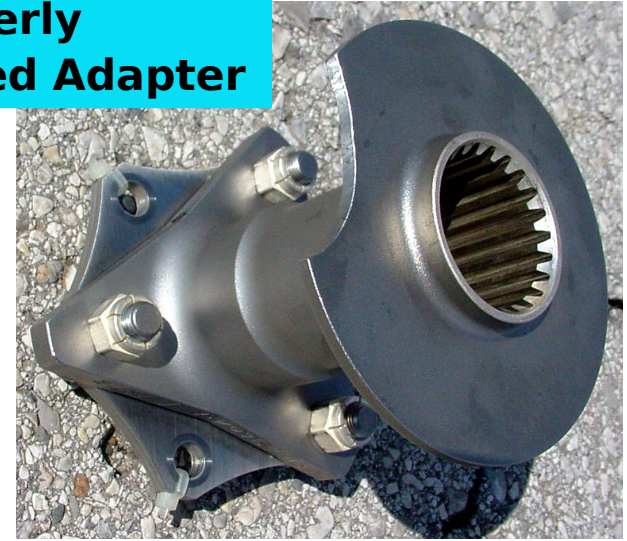
Findings

- Periodic vibration checks expanded to in flight regimes revealed HSS levels as high as 26 g's
- Balancing procedures at vendor and depot facilities found to be inadequate

Resolution

- Balance machines updated and match set balancing implemented

Improperly Balanced Adapter



Electrical Generator Failures

Problem

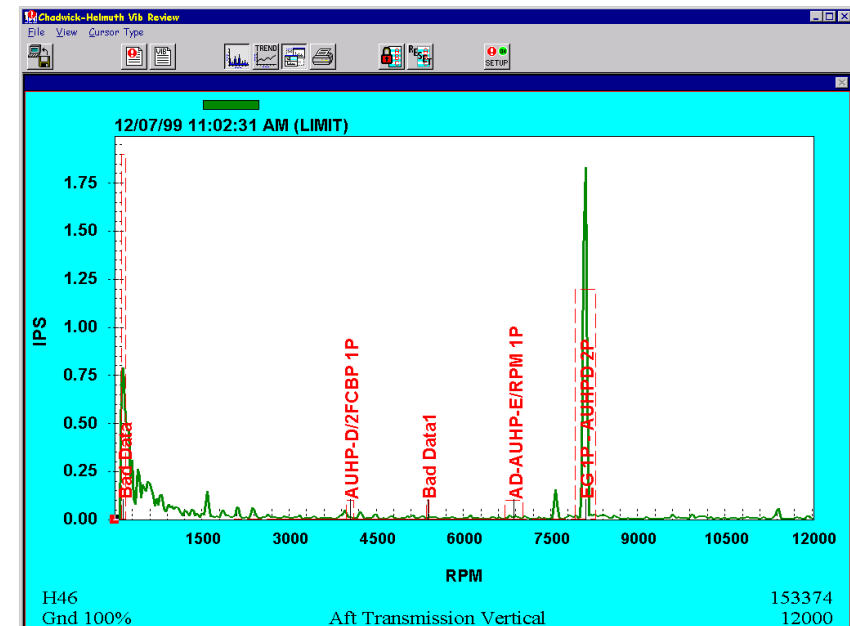
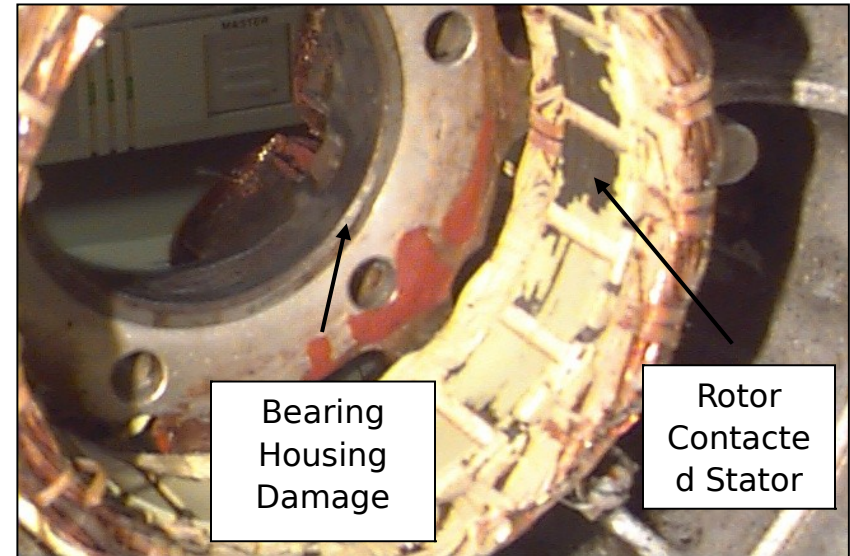
- Catastrophic generator failures
- Failures causing in-flight hazards & emergency shutdown

Findings

- Change in scheduled maintenance allowing generators to run to failure

Resolution

- New vibration check procedure identifies degraded generators before catastrophic failure
- Scheduled overhaul replaced with vibration check (on-condition)
- Saves ~900K per year



AFT Transmission Life Extensions

Problem

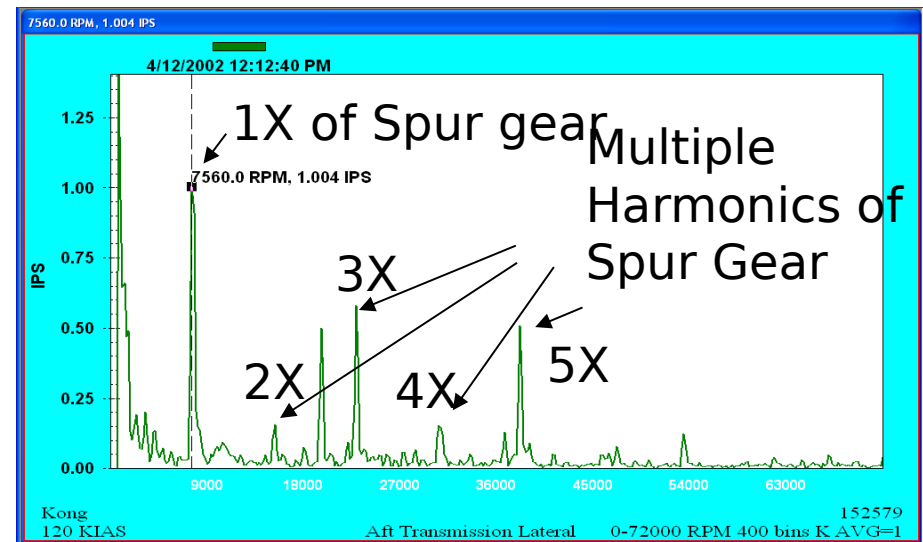
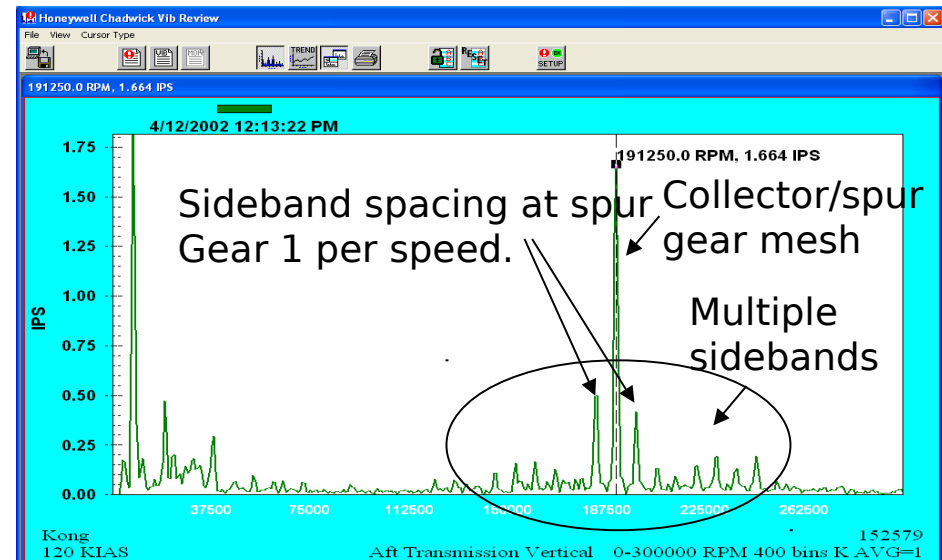
- High time of Aft Xmsn is 900 hours
- Life extensions granted without data
- Untimely failures resulted

Findings

- Failures can be detected by vibration analysis

Resolution

- Mandatory submittal of vibration data required for life extensions
- If able to eliminate resonance the Xmsn may be able to extend to 1800 hours



Excessive Engine Vibrations

Problem

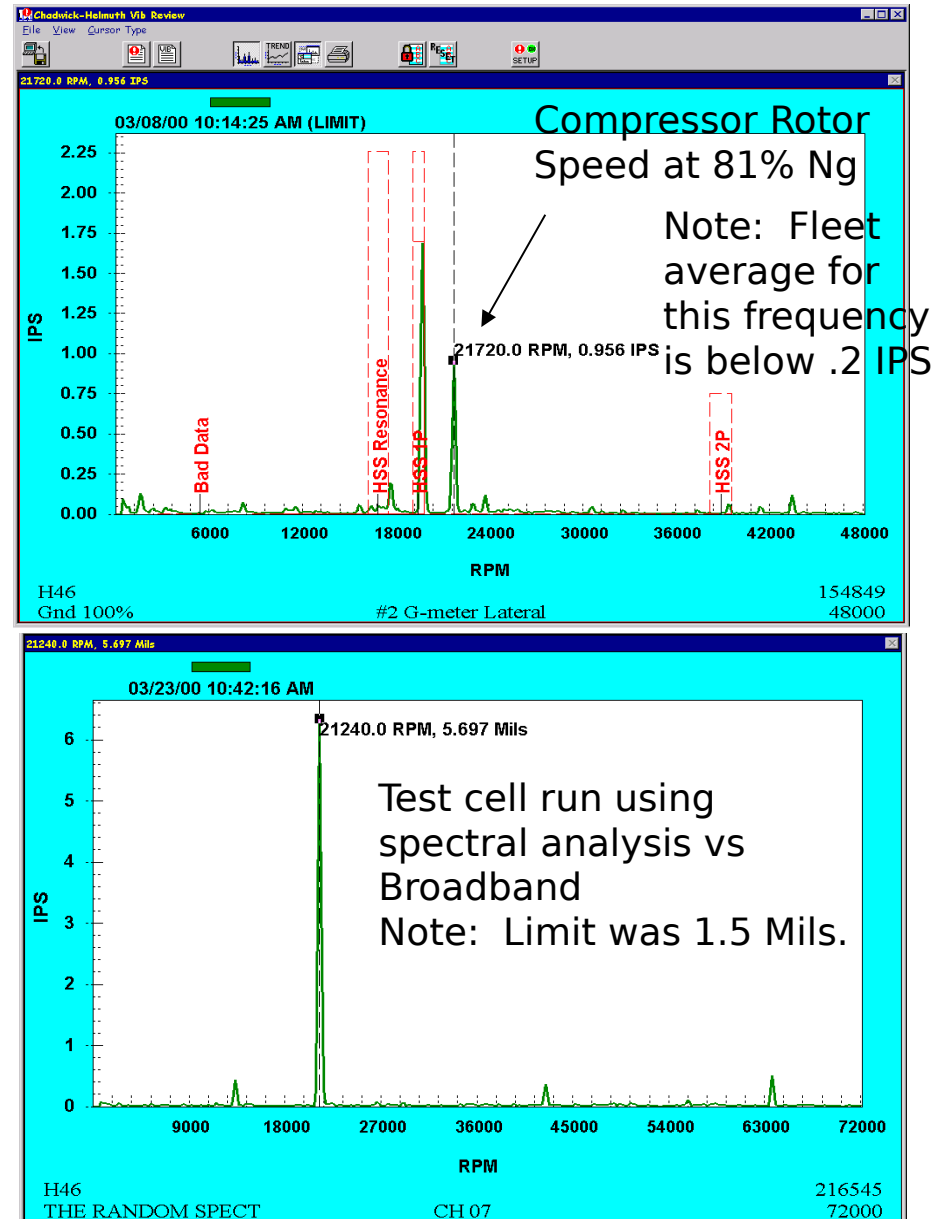
- Loud audible howl on newly overhauled engine

Findings

- All test cell runs passed
- Mils Broadband was acceptance criteria
- Mobile test cell failed to identify problem
- Poorly balanced compressor rotor caused damage to 8th, 9th, and 10th stages of the rotor

Resolution

- 3 spectral analyzer fielded in test cells for data collection



Phase III

Justification for Hardwiring of Aircraft



Eng Drive Shaft Catastrophic Failure

Problem

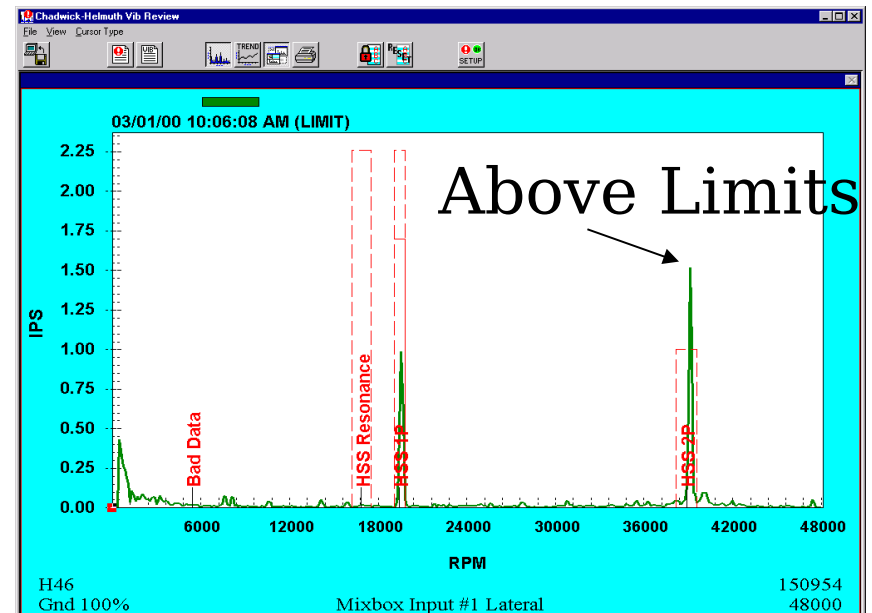
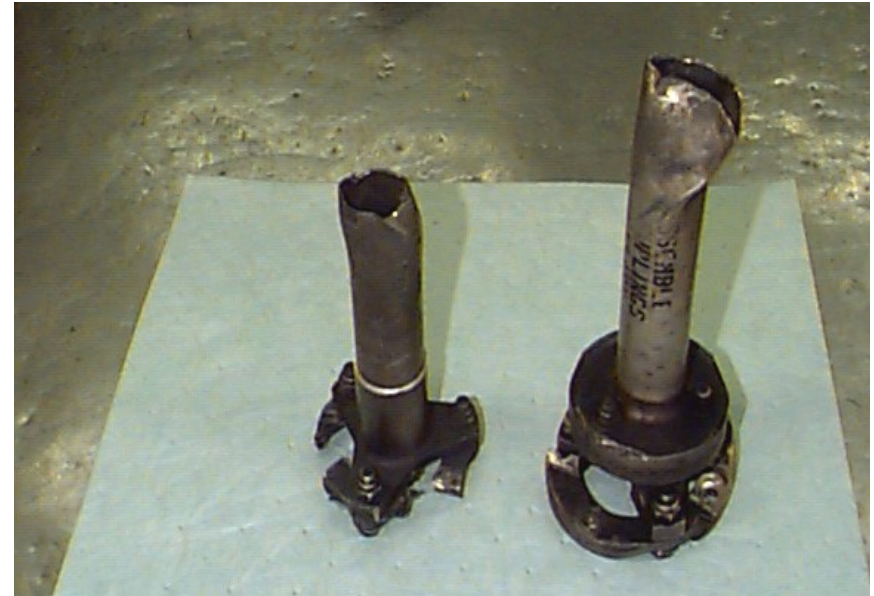
- Test of #1 & #2 Engine Drive Shafts indicated misalignment on Engine #1

Findings

- Maintenance performed and aircraft released to serviceability
- #2 Engine Drive shaft failed catastrophically in flight
- Equipment installed incorrectly
- Maintenance performed on incorrect shaft

Resolution

- Human error allowed component to fly to failure
- Hardwiring would have prevented this error



- **Purchased kits to install sensors and wiring in approximately 180 aircraft (1.2M, FY 00)**
- **Prepares aircraft for onboard vibration system expansion**
- **Solved fleet driven complaints about SE wear and tear**

Phase IV

Test Cell Expansion



- **Began initial data collection using 3 8500C spectrum analyzers in late 1999**
 - 2 at NADEP Cherry Point
 - 1 at MALS-29/26
- **Noted significant gains by progressing towards spectral analysis**
 - Provided means to isolate specific frequency(s) yielding greatest amount of vibration
 - Significant unbalance conditions noted on main rotating components
 - ◆ New balance machines and procedures incorporated (350K)
- **COTS spectrum analyzers (VXP) fielded in early 2001 (235K, FY 01)**
- **Spectral analysis now used on all test cells to accept/reject engines**

- **Vibration data collected by Broadband system had falsely led fleet to reject multiple Power Turbine assemblies due to excessive vibration**
 - GE proposed an expensive redesign of the PT bearing/housing as a viable solution
- **COTS vibration analyzers uncovered the dominant frequency causing the vibration, which was the Gas Generator Turbine**
 - Immediately avoided countless PT overhauls (fleet wide)
 - GE ceased bearing redesign effort
 - Yearly savings realized, using spectral analysis, due to fault isolation capabilities
 - ♦ PT Rotor Cost: \$47,757/unit
 - ♦ PT Assembly Cost: \$99,264/assembly

Substantial Finding - Impending Bearing Failure

Problem

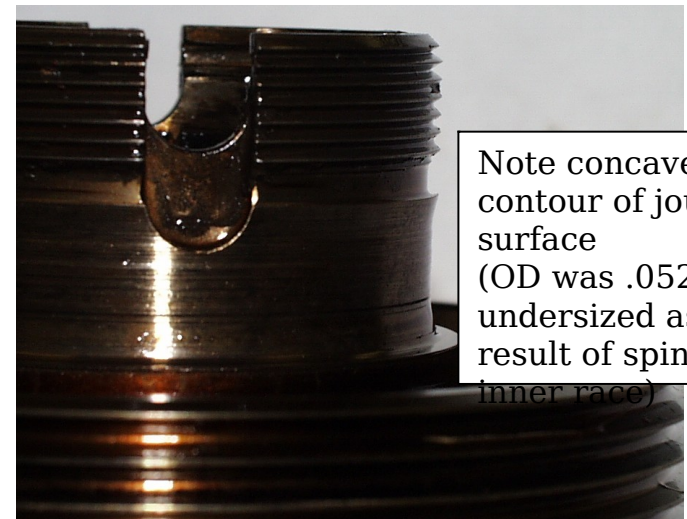
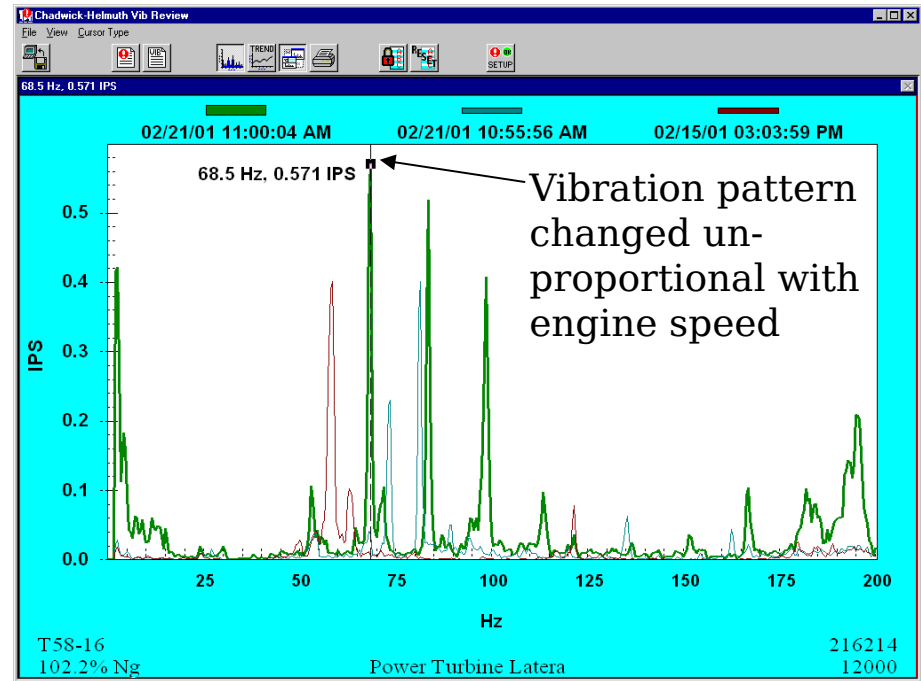
- Engine passed test cell based upon Broadband vibration test
- Rejected on-wing due to audible howling

Findings

- Spectral analysis indicated Gas Generator Turbine as the problem area
- Troubleshooting with the spectral analysis concluded to non-synchronous behavior, indicating spinning bearing race
- Large fragments found upon teardown
- Test cell Broadband equipment not properly configured

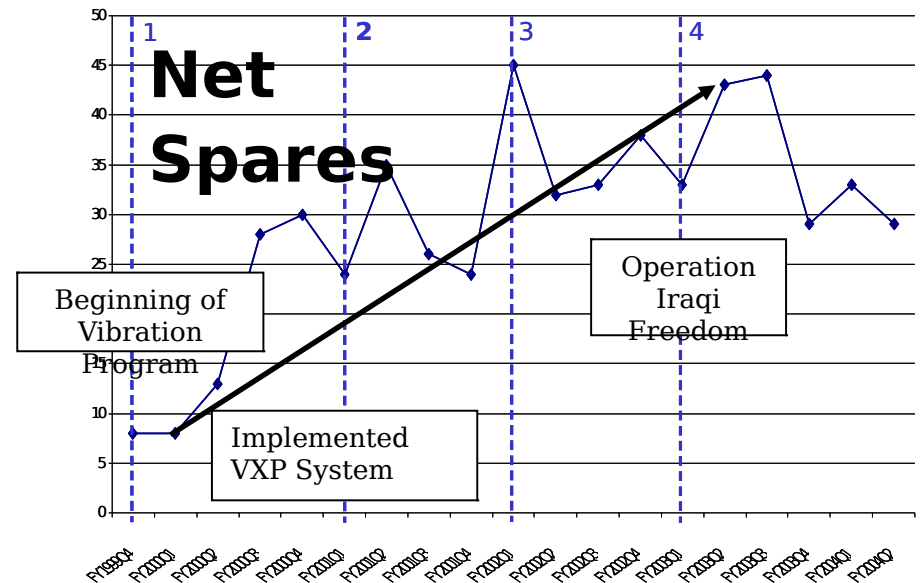
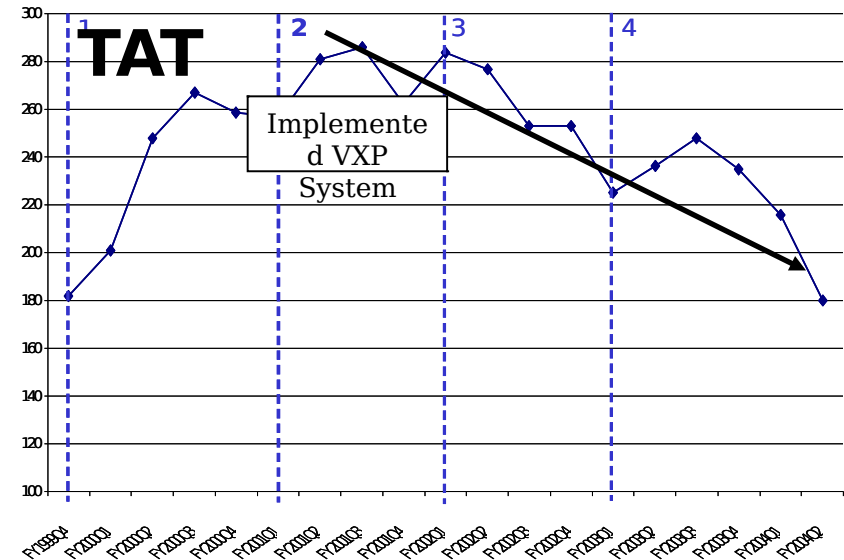
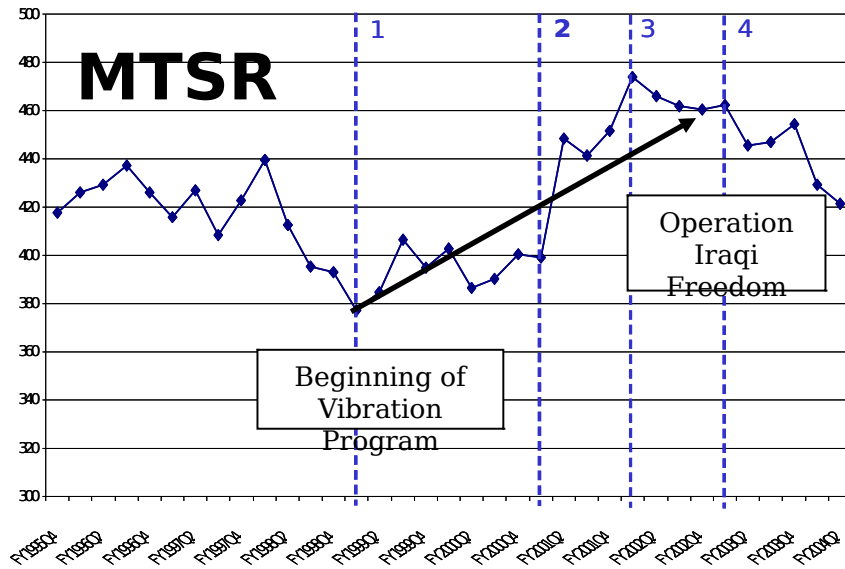
Resolution

- Early detection of bearing wear possible with spectral analysis, avoiding potential catastrophic failure on-wing



Return on Investment

- **Spectral analyzer implementations yield significant benefits**
 - Increased engine avg. mean time since repair
 - Decreased engine turn around time
 - Increased average net spares available



Phase V

On-Board Systems Increase Safety



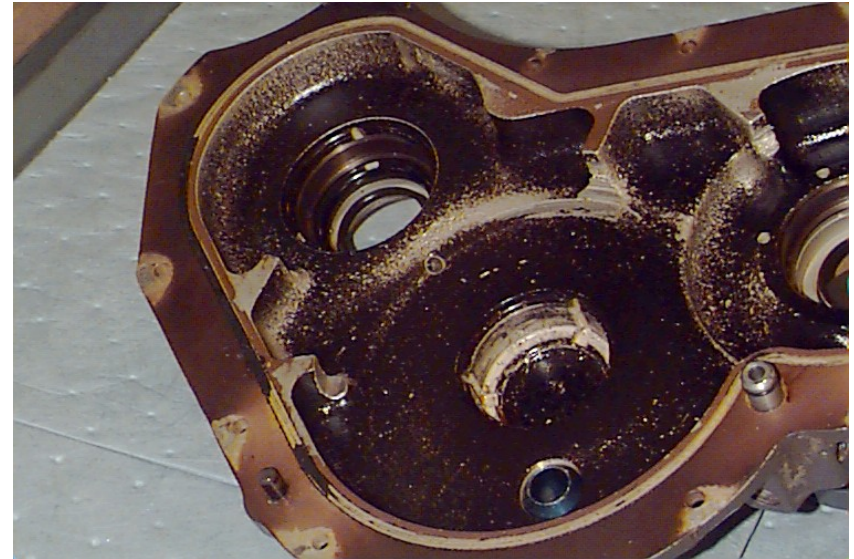
Aft Transmission Bearing Failure

Problem

- Aft Transmission Smoking in flight

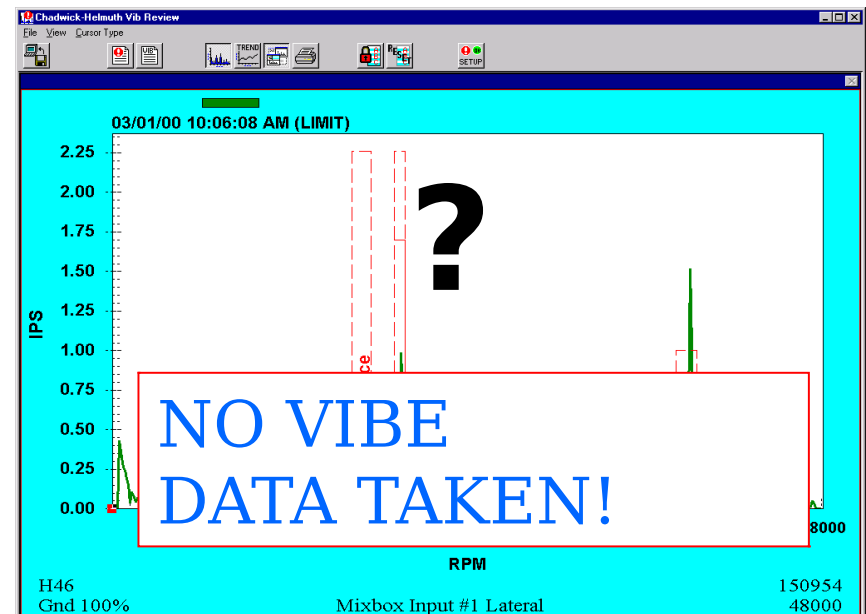
Findings

- Bearing Failure
- Gearbox failed after bearing failure resulting in sheared lube pump shaft
- Loss of pump caused over temp in flight



Resolution

- 100 Phase check was not performed
- Automated on-board system would have prevented this human induced error



Head Bearing Failure

Problem

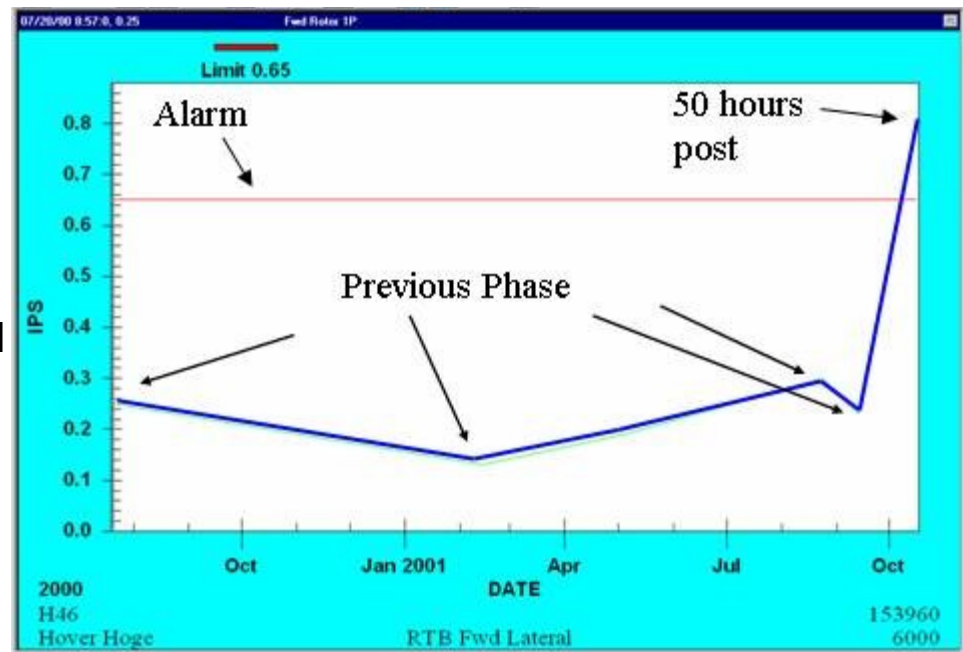
- Post Phase vibration checked and passed
- Significant increases in vibration reported by the crew after only a few hours of flight

Findings

- Repeated vibration checks verified the crew discrepancy
- Vib levels had risen over a short period of time
- Sr. Squadron officer instructed the aircraft to remain in service
- 7 hours later the flight was aborted by the Air Boss - aircraft significantly shaking on deck
- Failed head seal and bearing found
- Oil leakage problem was ignored
- Lack of lubrication led to failure
- Rotor head hub was close to total failure that would have resulted in a complete loss of the aircraft & crew

Resolution

- On-board equipment would have indicated the problem immediately



Phase IV:

On Board System Aircraft Integrated Maintenance System



Eliminate Support Equipment

- **Honeywell Rotor Track and Balance - Model 8500C+**
- **Vibration Signature Carry - On Accessory Kit**
- **Howell Instruments Engine Check System - NP600**
- **Purchase (FY 03 - 08)**



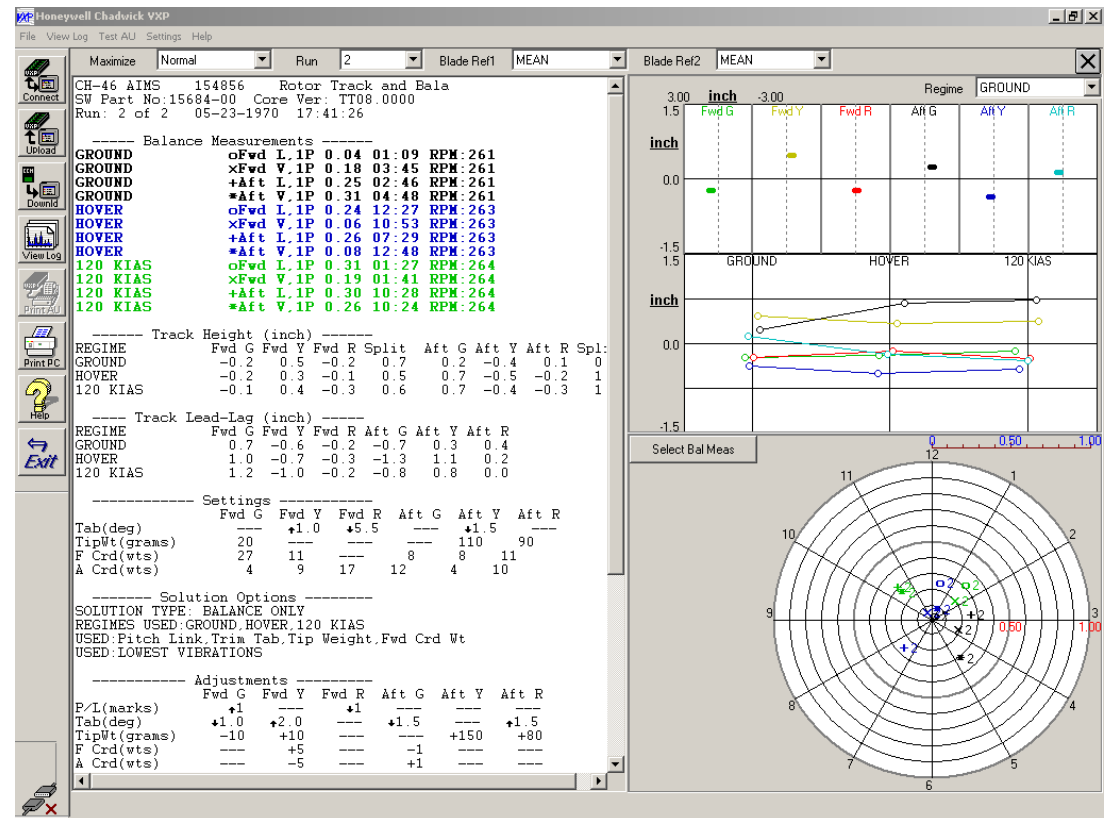
Logistics Savings Realized

- **Rotor Track & Balance**
- **Periodic Vibration Checks**
- **Continual Vibration Monitoring**
- **Engine Performance Checks with automatic nomograph and margin calculations**
- **Continual Aircraft & Engine Parameter Monitoring**
- **1553 Databus interface**
- **Interface to Control Display Navigational Unit (CDNU) via the 1553 databus**
- **On Board Go/No Go indications with simple user interface for the aircrew**
- **Ground Station Software with Go/No Go indications, data archival, data review & analysis**

Features with immediate payback

RT&B Displays

- Polar Plot Display
- Track Display
- Measurements & Solution Display
- Adjustments



Improves Troubleshooting Capability

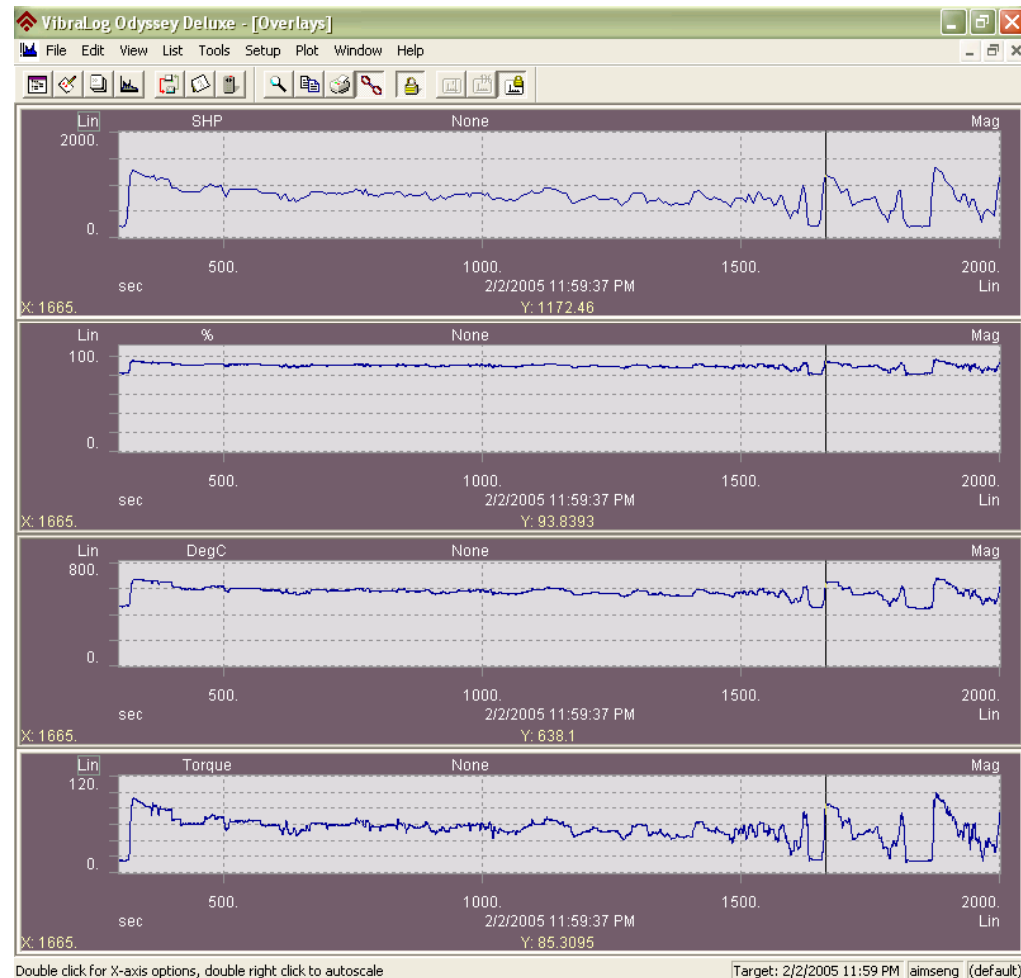
- **User definable configurations via Engineering Ground Station Software**
- **Multiple alarming levels, which drive visibility to aircrew**
 - Master Caution Panel
 - On CDNU Display
 - On AIMS Acquisition Unit
 - On Ground Station



Immediate Feedback of Alarm Conditions

- **Monitors:**

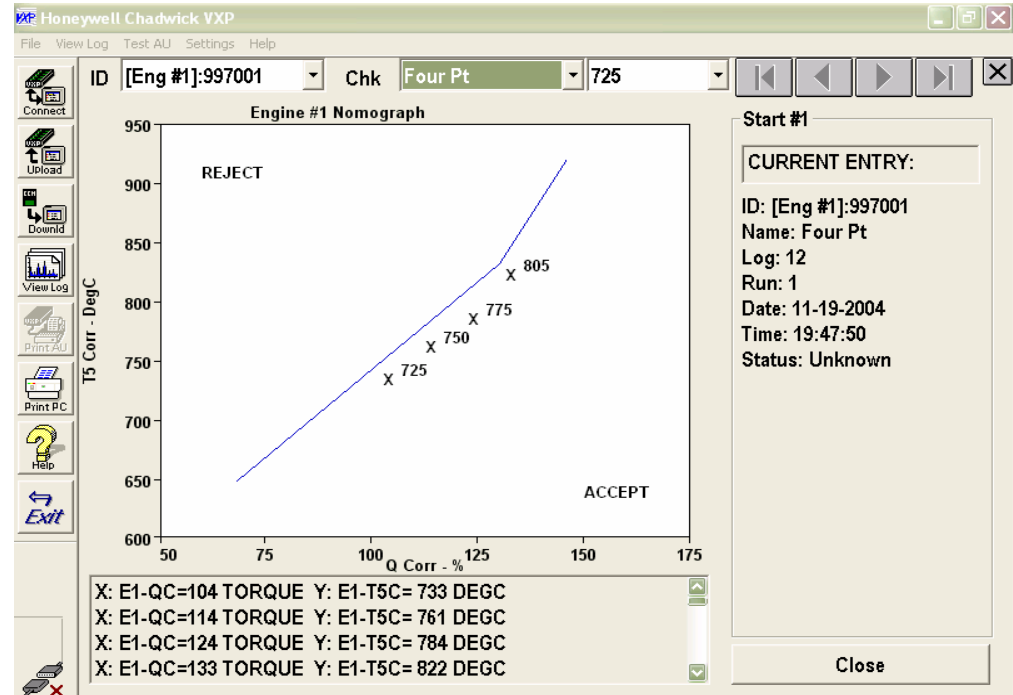
- **Engine and Drivetrain Vibration Levels**
- **Overspeeds**
- **Overtorques**
- **Overtemperatures**
- **Chip and Debris Screen States**
- **Oil Temperature and Pressure**
- **Engine Performance Margin**
- **Air Data (OAT, PA, KIAS via 1553B data bus interface)**



Increasing Safety & Reliability

Engine Check Displays

- Engine performance assessed on-board, resulting in immediate feedback of acceptability
- Complete post maintenance check flight engine setup



- Migrating towards fully automated performance margin on the fly
 - Potentially eliminating phase performance check requirement
 - Potentially aiding mission planning efforts

Eliminate Manual Data Entry and Plotting of Data Points

- **Annual FCF hours using AIMS will be reduced by 1117 hrs resulting in a savings of \$10,938,505 based on FY04 data**
- **FCF setup time; In addition, the time savings will easily surpass 8,000 man hours annually required to set up for FCF's**
- **SE savings: calibration, repair, fleet readiness**
- **AIMS monitor feature has potential to uncover component anomalies, prior to catastrophic failure, inherently save parts and will increase safety**

Conclusion



- **Automation is good to a point**
- **No COTS system is 100% ready to go**
- **Demand control of configurations (routes & limits)**
- **Control getting drowned in mass amounts of data**
- **The system must cater to the operator and maintainer**
- **More is not necessarily better**
- **Must be simple at end user**
- **Must inform the operator/maintainer of pending problems or failures**
- **Grow the system as lessons are learned**
- **Off site analysis is not practical**
- **Must conform to new software requirements - NMCI**

Understand how your system works for you

- **Advanced Gearbox Diagnostics**
- **Monitoring of flight controls**
- **Flight regime recognition for engine performance calculations**
- **Automation of data management, diagnostics and prognostics**
- **RT&B “SmartChart” Technology - Tell the maintainer what is wrong with the aircraft**

Benefits are tangible

- **Significant Cost Savings**
- **Achieved highest readiness rating**
- **Engine availability improved**
- **Back shop procedures improved**
- **Safety of flight improved**

We have realized a significant return

Questions?

